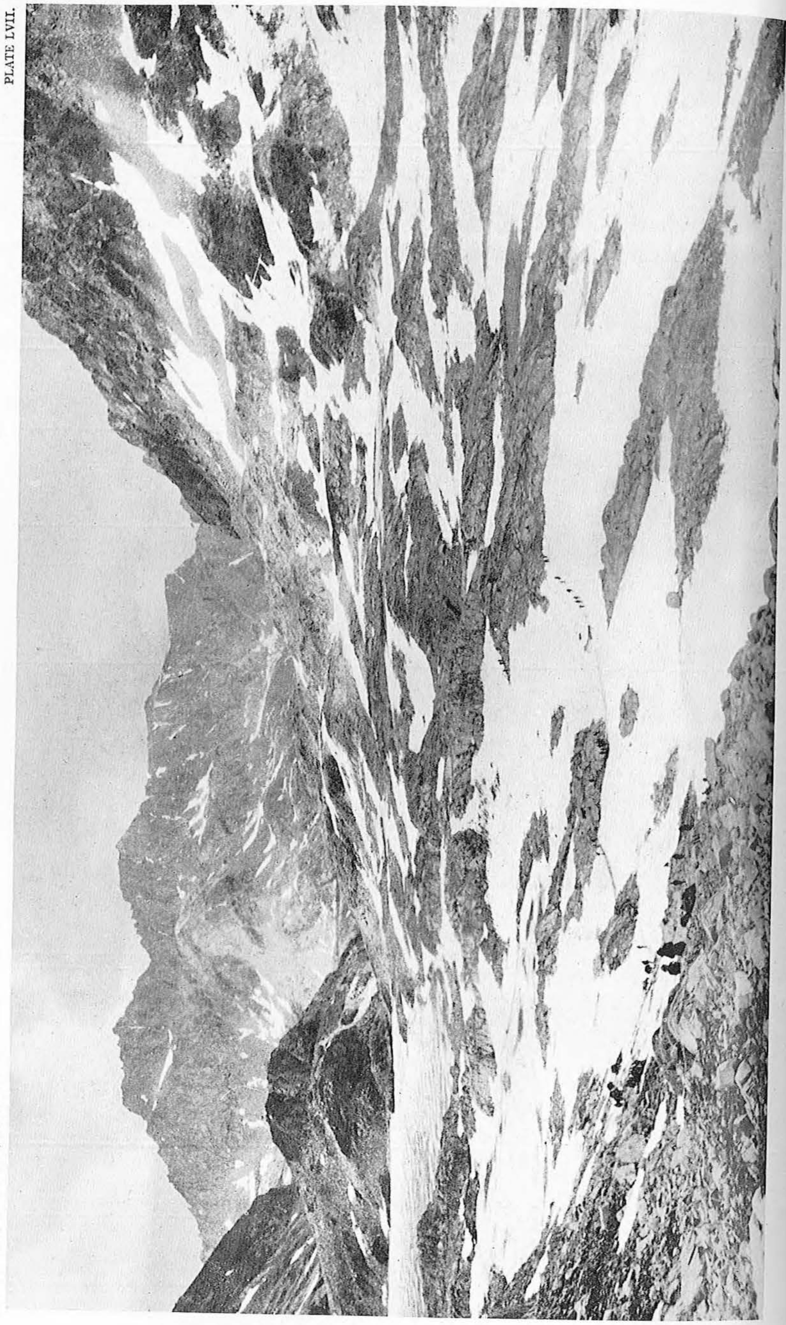
1-1-1921

# Studies in the Sierra. No. VII. - Mountain Building.

John Muir

PLATE LVII.



HEADWATERS OF THE MIDDLE FORK OF KINGS RIVER FROM MUIR PASS
Photo by Rodney L. Glisan

# STUDIES IN THE SIERRA*

By John Muir

## NO. VII.—MOUNTAIN-BUILDING

THIS study of mountain-building refers particularly to that portion of the range embraced between latitudes 36° 30′ and 39°. It is about 200 miles long, sixty wide, and attains an elevation along its axis of from 8000 to nearly 15,000 feet above the level of the sea. The individual mountains that are distributed over this vast area, whether the lofty and precipitous alps of the summit, the more beautiful and highly specialized domes and mounts dotted over the undulating flanks, or the huge bosses and angles projecting horizontally from the sides of cañons and valleys, have all been sculptured and brought into relief during the glacial epoch by the direct mechanical action of the ice-sheet, with the individual glaciers into which it afterward separated. Our way to a general understanding of all this has been made clear by previous studies of valley formations—studies of the physical characters of the rocks out of which the mountains under consideration have been made, and of the widely contrasted methods and quantities of glacial and post-glacial denudation.

Notwithstanding the accessibility and imposing grandeur of the summit alps, they remain almost wholly unexplored. A few nervous raids have been made among them from random points adjacent to trails, and some of the more easily accessible, such as mounts Dana, Lyell, Tyndall, and Whitney, have been ascended, while the vast wilderness of mountains in whose fastnesses the chief tributaries of the San Joaquin and Kings rivers take their rise, have been beheld and mapped from a distance, without any attempt at detail. Their echoes are never stirred even by the hunter's rifle, for there is no game to tempt either Indian or white man as far as the frosty lakes and meadows that lie at their bases, while their avalanche-swept and crevassed glaciers, their labyrinths of yawning gulfs and crumbling precipices, offer dangers that only powerful motives will induce any-one to face.

* Reprinted from *The Overland Monthly* of January, 1875.

The view southward from the colossal summit of Mount Humphreys is indescribably sublime. Innumerable gray peaks crowd loftily into the keen azure, infinitely adorned with light and shade; lakes glow in lavish abundance around their bases; torrents whiten their denuded gorges; while many a glacier and bank of fountain *névé* leans back in their dark recesses. Awe-inspiring, however, as these vast mountain assemblies are, and incomprehensible as they may at first seem, their origin and the principal facts of their individual histories are problems easily solved by the patient student.

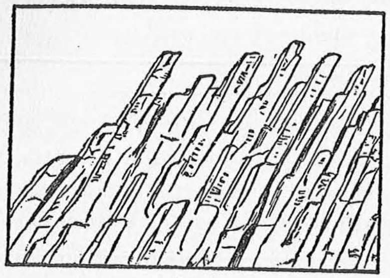


FIG. 1

Beginning with pinnacles, which are the smallest of the summit mountainets: no geologist will claim that these were formed by special upheavals, nor that the little chasms which separated them were formed by special subsidences or rivings asunder of the rock; because many of these chasms are as wide at the bottom as at the top, and scarcely exceed a foot in depth; and many may be formed artificially by simply removing a few blocks that have been loosened.

The Sierra pinnacles are from less than a foot to nearly a thousand feet in height, and in all the cases that have come under my observation their forms and dimensions have been determined, not by cataclysmic fissures, but by the gradual development of orderly joints and cleavage planes, which gave rise to leaning forms where the divisional planes are inclined, as in Figure 1, or to vertical where the planes are vertical, as in Figure 2. Magnificent crests tipped with leaning pinnacles adorn the jagged flanks of Mount Ritter, and majestic examples of vertical pinnacle architecture abound among the lofty mountain cathedrals on the heads of Kings and Kern rivers. The minarets to the south of Mount Ritter are an imposing series of partially

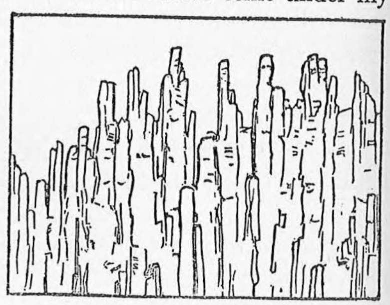


FIG. 2



separate pinnacles about 700 feet in height, set upon the main axis of the range. Glaciers are still grinding their eastern bases, illustrating in the plainest manner the blocking out of these imposing features from the solid. The formation of small peaklets that roughen the flanks of large peaks may in like manner be shown to depend, not upon any up-thrusting or down-thrusting forces, but upon the orderly erosion and transportation of the material that occupied the intervening notches and gorges.

The same arguments we have been applying to peaklets and pinnacles are found to be entirely applicable to the main mountain peaks; for careful detailed studies demonstrate that as pinnacles are separated by eroded chasms, and peaklets by notches and gorges, so the main peaks are separated by larger chasms, notches, gorges, valleys, and wide ice-womb amphitheaters. When across hollows we examine contiguous sides of mountains, we perceive that the same mechanical structure is continued across intervening spaces of every kind, showing that there has been a removal of the material that once filled them—the occurrence of large veins oftentimes rendering this portion of the argument exceedingly conclusive, as in two peaks of the Lyell group (Fig. 3), where the wide veins, N N, are continued across the valley from peak to peak. We frequently find rows of pinnacles set upon a base, the cleavage of which does not admit of pinnacle formation, and in an analogous way we find immense slate mountains, like Dana and Gibbs, resting upon a plain granite pavement, as if they had been formed elsewhere, transported and set down in their present positions, like huge erratic boulders. It appears, therefore, that the loftiest mountains as well as peaklets and pinnacles of the summit region are residual masses of the once solid wave of the whole range, and that all that would be required to unbuild and obliterate these imposing structures would simply be the filling up of the labyrinth of intervening chasms, gorges, cañons, etc., which divide them, by the restoration of rocks that have disappeared. Here the important question comes up, What has become of the missing material, not the

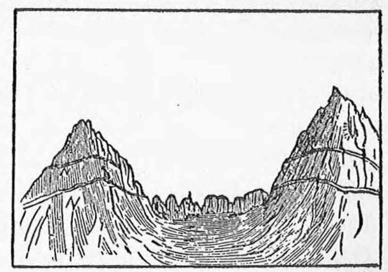


FIG. 3

millionth part of which is now to be seen? It has not been engulfed, because the bottoms of all the dividing valleys and basins are unmistakably solid. It must, therefore, have been carried away; and because we find portions of it scattered far and near in moraines, easily recognized by peculiarities of mineralogical composition, we infer that glaciers were the transporting agents. That glaciers have brought out the summit peaks from the solid with all their imposing architecture, simply by the formation of the valleys and basins in which they flowed, is a very important proposition, and well deserves careful attention.

We have already shown, in studies Nos. III and IV, that all the valleys of the region under consideration, from the minute striae and scratches of the polished surface less than a hundredth part of an inch in depth, to the Yosemitic gorges half a mile or more in depth, were all eroded by glaciers, and that post-glacial streams, whether small glancing brooklets or impetuous torrents, had not yet lived long enough to fairly make their mark, no matter how unbounded their eroding powers may be. Still, it may be conjectured that preglacial rivers furrowed the range long ere a glacier was born, and that when at length the ice-winter came on with its great skyfuls of snow, the young glaciers crept into these river channels, overflowing their banks, and deepening, widening, grooving, and polishing them without destroying their identity. For the destruction of this conjecture it is only necessary to observe that the trends of the present valleys are strictly glacial, and glacial trends are extremely different from water trends; preglacial rivers could not, therefore, have exercised any appreciable influence upon their formation.

Neither can we suppose fissures to have wielded any determining influence, there being no conceivable coincidence between the zigzag and apparently accidental trends of fissures and the exceedingly specific trends of ice-currents. The same argument holds good against primary foldings of the crust, dislocations, etc. Finally, if these valleys had been hewn or dug out by any preglacial agent whatever, traces of such agent would be visible on mountain masses which glaciers have not yet segregated; but no such traces of valley beginnings are anywhere manifest. The heads of valleys extend back into mountain masses just as far as glaciers have gone and no farther.

Granting, then, that the greater part of the erosion and transportation of the material missing from between the mountains of the summit was effected by glaciers, it yet remains to be considered what agent or agents shaped the upper portions of these mountains, which bear no traces of glacial action, and which probably were always, as they now are, above the reach of glaciers. Even here we find the glacier to be indirectly the most influential agent, constantly eroding backward, thus undermining their bases, and enabling gravity to drag down large masses, and giving greater effectiveness to the winter avalanches that sweep and furrow their sides. All the summit peaks present a crumbling, ruinous, unfinished aspect. Yet they have suffered very little change since the close of the glacial period, for if denudation had been extensively carried on, their separating pits and gorges would be choked with *débris;* but, on the contrary, we find only a mere sprinkling of post-glacial *detritus,* and that the streams could not have carried much of this away is conclusively shown by the fact that the small lake-bowls through which they flow have not been filled up.



In order that we may obtain clear conceptions concerning the methods of glacial mountain-building, we will now take up the formation of a few specially illustrative groups and peaks, without, however, entering into the detail which the importance of the subject deserves.

The Lyell group lies due east from Yosemite Valley, at a distance of about sixteen miles in a straight course. Large tributaries of the Merced, Rush, Tuolumne, and San Joaquin rivers take their rise amid its ice and snow. Its geographical importance is further augmented by its having been a center of dispersal for some of the largest and most influential of the ancient glaciers. The traveler who undertakes the ascent of Mount Lyell, the dominating mountain of the group, will readily perceive that, although its summit is 13,200 feet above the level of the sea, all that individually pertains to it is a small residual fragment less than a thousand feet high, whose existence is owing to slight advantages of physical structure and position with reference to the heads of ancient glaciers, which prevented its being eroded and carried away as rapidly as the common mountain mass circumjacent to it.

Glacier wombs are rounded in a horizontal direction at the head, for the same reason that they are at the bottom; this being the form that offers greatest resistance to glacial erosion. The semicircular outline thus determined is maintained by the glaciers in eroding their way backward into the mountain masses against which they head; and where these curved basins have been continued quite through the axis of the chain or spur, separate mountains have been produced, the degree of whose individuality depends upon the extent and variation of this erosion. Thus, let A B (Fig. 4) represent a section of a portion of the summit of a mountain chain, and C D E F G H, etc., the wombs of glaciers dead or active, then the residual masses 1 2 3 will be the so-called mountains.

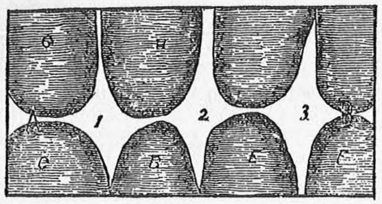



Fig. 4

It may well excite surprise that snow collected in these fountain-wombs should pass so rapidly through the *névé* condition, and begin to erode at the very head; that this, however, was the case is shown by unmistakable traces of that erosion upon the sides and heads as well as bottoms of wombs now empty. The change of climate which broke up the glacial winter would obviously favor the earlier transformation of snow into eroding ice, and thus produce the present conditions as necessary consequences.

The geological effects of shadows in prolonging the existence and in guiding and intensifying the action of portions of glaciers are manifested in moraines, lake-basins, and the difference in form and sculpture between the north and south sides of mountains and valleys. Thus, the attentive observer will perceive that the architecture of deep valleys trending in a northerly and southerly direction, as Yosemite, abounds in small towers, crests, and shallow flutings on the shadowy south side, while the sun-beaten portions of the north walls are comparatively plain. The finer sculpture of the south walls is directly owing to the action of *small shadow-glacierets*—which lingered long after the disappearance of the main glaciers that filled the valleys from wall to wall.

Every mountaineer and Indian knows that high mountains are more easily ascended on the south than on the north side. Thus, the Hoffmann spur may be ascended almost anywhere from the south on horseback, while it breaks off in sheer precipices on the north. There is not a mountain peak in the range which does not bear witness in sculpture and general form to this glacial-shadow action, which in many portions of the summit may still be observed in operation. But it is only to the effects of shadows in the segregation of mountain masses that I would now direct special attention. Figure 5 is a map of the Merced range adjacent to Yosemite Valley, with a portion of the ridge which unites it to the main axis. The arrows indicate the direction of extension of the deep glacial amphitheaters, and it will be at once seen that they all point in a southerly direction beneath the protection of shadows cast by the peaks and ridges. Again, it will be seen that because the Merced spur (S P) trends in a northerly direction, its western slopes are in shadow in the forenoon, its eastern in the afternoon, consequently it has a series of glacial wombs on *both* sides; but because the ridge (P G) trends in an easterly direction, its southern slopes are scarcely at all in shadow, consequently deep glacial wombs occur *only* upon the *northerly* slopes. Still further, because the Merced spur (S P) trends several degrees west of north, its eastern slopes are longer in shadow than the western, consequently the ice-wombs of the former are deeper and



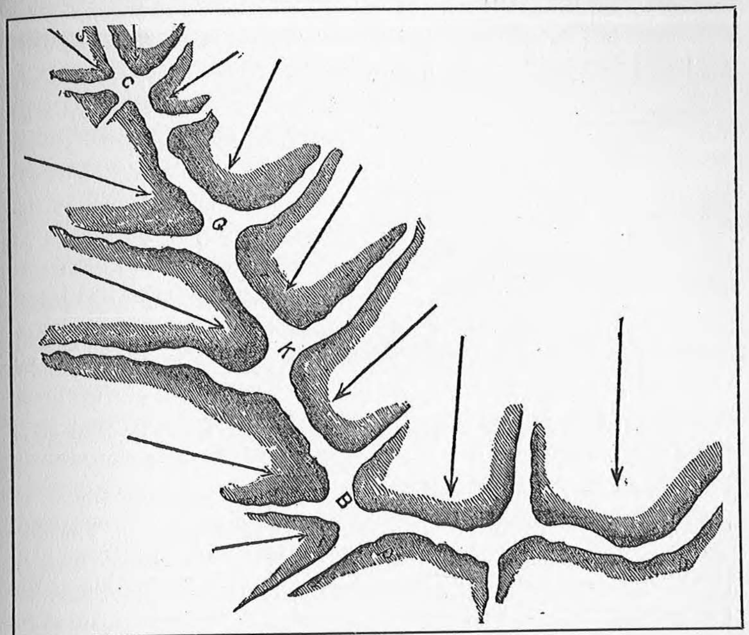



Fig. 5

their head-walls are sheerer; and in general, because the main axis of the Sierra has a northwesterly direction, the summit peaks are more precipitous on the eastern than on the western sides.

In the case of ice-wombs on the north side of a mountain equally shadowed on the east and west, it will be found that such wombs, other conditions being equal, curve back in a direction a little to the west of south, because forenoon sunshine is not so strong as afternoon sunshine. The same admirable obedience to shadows* is conspicuous in all parts of the summits of the range. Now, *glaciers are the only eroders that are thus governed by shadows.*

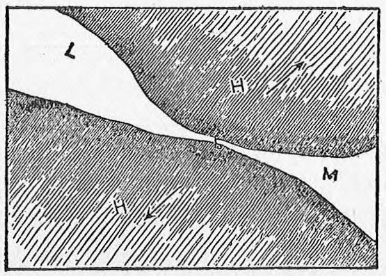



FIG. 6

Figure 6 is a section illustrating the mode in which the heads (H H) of tributaries of the Tuolumne and Merced glaciers have eroded and segregated the mountain mass (L M) into two mountains—namely, Lyell and McClure—by moving backward until they met at C, leaving only the thin crest as it now exists.

Mount Ritter lies a few miles to the south of Lyell, and is readily accessible to good mountaineers by way of the Mono plains. The student of mountain-building will find it a kind of text-book, abounding in wonderfully clear and beautiful illustrations of the principles of Sierra architecture we have been studying. Upon the north flank a small active glacier may still be seen at work blocking out and separating a peak from the main mass, and its whole surface is covered with clearly cut inscriptions of the frost, the storm-wind, and the avalanche. Though not the very loftiest, Ritter is to me far the noblest mountain of the chain. All its neighbors stand well back, enabling it to give full expression to its commanding individuality; while living glaciers, rushing torrents, bright-eyed lakes, gentian meadows; flecks of lily and anemone, shaggy thickets and groves, and polleny zones of sun-filled *compositae,* combine to irradiate its massive features, and make it as beautiful as noble.

The Merced spur (see Fig. 5), lying about ten miles to the south-

* For further illustrations of the above observations on shadows, I would refer the reader to Gardiner and Hoffman's map of the Sierra adjacent to Yosemite Valley, or, still better, to the mountains themselves.



east of Yosemite Valley and about the same distance from the main axis, presents a finely individualized range of peaks, 11,500 to 12,000 feet high, hewn from the solid. The authors of this beautiful piece of sculpture were two series of tributaries belonging to the glaciers of the Nevada and Illilouette.

The truly magnificent group of nameless granite mountains stretching in a broad swath from the base of Mount Humphreys forty miles southward, is far the largest and loftiest of the range. But when we leisurely penetrate its wild recesses, we speedily perceive that, although abounding in peaks 14,000 feet high, these, individually considered, are mere pyramids, 1000 to 2000 feet in height, crowded together upon a common base, and united by jagged columns that swoop in irregular curves from shoulder to shoulder. That all this imposing multitude of mountains was chiseled from one grand preglacial mass is everywhere proclaimed in terms understandable by mere children.

Mount Whitney lies a few miles to the south of this group, and is undoubtedly the highest peak of the chain, but, geologically or even scenically considered, it possesses no special importance. When beheld either from the north or south, it presents the form of a helmet, or, more exactly, that of the Scotch cap called the "Glengarry." The flattish summit curves gently toward the valley of the Kern on the west, but falls abruptly toward Owens River Valley on the east, in a sheer precipice near 2000 feet deep. Its north and southeast sides are scarcely less precipitous, but these gradually yield to accessible slopes, round from southwest to northwest. Although highest of all the peaks, Mount Whitney is far surpassed in colossal grandeur and general impressiveness of physiognomy, not only by Mount Ritter, but by mounts Dana, Humphreys, Emerson, and many others that are nameless. A few meadowless lakes shine around its base, but it possesses no glaciers, and, toward the end of summer, very litle snow on its north side, and none at all on the south. Viewed from Owens Valley, in the vicinity of Lone Pine, it appears as one of many minute peaklets that adorn the massive uplift of the range like a cornice. Toward the close of the glacial epoch, the gray porphyritic summit of what is now Mount Whitney peered a few feet above a zone of *névé* that fed glaciers which descended into the valleys of the Owens and Kern rivers. These, eroding gradually deeper, brought all that specially belongs to Mount Whitney into relief. Instead of a vast upheaval, it is merely a remnant of the common mass of the range, which, from relative conditions of structure and position, has suffered a little less degradation than the portions circumjacent to it.

Regarded as measures of mountain-building forces, the results of erosion are negative rather than positive, expressing more directly what has *not* been done than what *has* been done. The difference between the peaks and the passes is not that the former are elevations, the latter depressions; both are depressions, differing only in degree. The abasement of the peaks having been effected at a slower rate, they were, of course, left behind as elevations.

The transition from the spiky, angular summit mountains to those of the flanks with their smoothly undulated outlines is exceedingly well marked; weak towers, pinnacles, and crumbling, jagged crests at once disappear,* leaving only hard, knotty domes and ridge-waves as geological illustrations, on the grandest scale, of the survival of the strongest.

Figure 7 illustrates, by a section, the general cause of the angularity of summit mountains, and curvedness of those of the flanks;

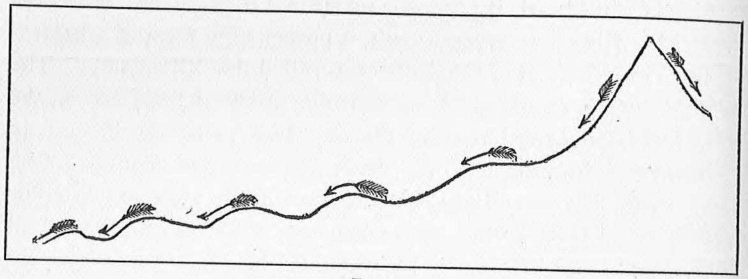


FIG. 7

the former having been *down*-flowed, the latter *over*-flowed. As we descend from the alpine summits on the smooth pathways of the ancient ice-currents, noting where they have successively denuded the various rocks—first the slates, then the slaty-structured granites, then the curved granites—we detect a constant growth of specialization and ascent into higher forms. Angular masses, cut by cleavage planes begin to be comprehended in flowing curves. These masses, in turn, become more highly organized, giving rise by the most gradual approaches to that magnificent dome scenery for which the Sierra is unrivaled. In the more strongly specialized granite regions,

* For exceptions to this general law, real or apparent, see Study No. I.



the features, and, indeed, the very existence, of overflowed mountains are in great part due neither to ice, water, nor any eroding agent whatsoever, but to building forces—crystalline, perhaps—which put them together and bestowed all that is more special in their architectural physiognomy, while they yet lay buried in the common fountain mass of the range.

The same silent and invisible mountain-builders performed a considerable amount of work upon the down-flowed mountains of the summit, but these were so weakly put together that the heavy hand of the glacier shaped and molded, without yielding much compliance to their undeveloped forms. Had the unsculptured mass of the range been everyway homogeneous, glacial denudation would still have produced summit mountains, differing not essentially from those we now find, but the rich profusion of flank mountains and mountainets, so marvelously individualized, would have had no existence, as the whole surface would evidently have been planed down into barren uniformity.

Thus the want of individuality which we have been observing among the summit mountains is obviously due to the comparatively uniform structure and erodibility of the rocks out of which they have been developed; their forms in consequence being greatly dependent upon the developing glaciers; whereas the strongly structured and specialized flank mountains, while accepting the ice-currents as developers, still defended themselves from their destructive and form-bestowing effects.

The wonderful adaptability of ice to the development of buried mountains, possessing so wide a range of form and magnitude, seems as perfect as if the result of direct plan and forethought. Granite crystallizes into landscapes; snow crystallizes above them to bring their beauty to the light. The grain of no mountain oak is more gnarled and interfolded than that of Sierra granite, and the ice-sheet of the glacial period is the only universal mountain eroder that works with reference to the grain. Here it smooths a pavement by slipping flatly over it, removing inequalities like a carpenter's plane; again it *makes* inequalities, gliding moldingly over and around knotty dome-clusters, groping out every weak spot, sparing the strong, crushing the feeble, and following lines of predestined beauty obediently as the wind.

Rocks are brought into horizontal relief on the sides of valleys wherever superior strength of structure or advantageousness of position admits of such development, just as they are elsewhere in a vertical direction. Some of these projections are of a magnitude that well deserves the name of *horizontal mountain.* That the variability of resistance of the rocks themselves accounts for the variety of these horizontal features is shown by the prevalence of this law. *Where the uniformity of glacial pressure has not been disturbed by the entrance of tributaries, we find that where valleys are narrowest their walls are strongest; where widest, weakest.*

In the case of valleys with sloping walls, their salient features will be mostly developed in an oblique direction; but neither horizontal nor oblique mountainets or mountains can ever reach as great dimensions as the vertical, because the retreating curves formed in weaker portions of valley walls are less eroded the deeper they become, on account of receiving less and less pressure, while the alternating salient curves are more heavily pressed and eroded the farther they project into the past-squeezing glacier; thus tending to check irregularity of surface beyond a certain limit, which limit is measured by the resistance offered by the rocks to the glacial energy brought to bear upon them. So intense is this energy in the case of large steeply inclined glaciers, that many salient bosses are broken off on the lower or down-stream side with a fracture like that produced by blasting. These fractures occur in all deep Yosemitic cañons, forming the highest expressions of the intensity of glacial force I have observed.

The same tendency toward maintaining evenness of surface obtains to some extent in vertical erosion also; as when hard masses rise abruptly from a comparatively level area exposed to the full sweep of the overpassing current. If vertical cleavage be developed in such rocks, *moutonnéed* forms will be produced with a split face turned away from the direction of the flow, as shown in Figure 8, Study No. 1. These forms, measuring from a few inches to a thousand feet or more in height, abound in hard granitic regions. If no cleavage be developed, then long ovals will be formed, with their greater diameters extended in the direction of the current. The general tendency, however, in vertical erosion is to make the valleys deeper and ridges relatively higher, the ice-currents being constantly attracted to the valleys, causing erosion to go on at an accelerated rate, and drawn away from the resisting ridges until they emerge



from the ice-sheet and cease to be eroded; the law here applicable being, "to him that hath shall be given."

Thus it appears that, no matter how the preglacial mass of the range came into existence, all the separate mountains distributed over its surface between latitude 36° 30′ and 39°, whether the lofty alps of the summit, or richly sculptured dome-clusters of the flank, or the burnished bosses and mountainets projecting from the sides of valleys—all owe their development to the ice-sheet of the great winter and the separate glaciers into which it afterward separated. In all this sublime fulfillment there was no upbuilding, but a universal razing and dismantling, and of this every mountain and valley is the record and monument.

## TRAVEL

*To travel is to do, not only to see. To travel best is to be of the sportsmen of the road. To take a chance and win; to feel the glow of muscles too long unused; to sleep on the ground at night and find it soft; to eat, not because it is time to eat, but because one's body is clamoring for food; to drink where every stream and river is pure and cold; to get close to the earth and see the stars—this is travel.*

MARY ROBERTS RINEHART